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Principles of temperature control

Part 3 – Concept of reset and PID

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In part 2 of this series, basic control modes were discussed, ranging from on/off control through to basic proportional control and ending off with an example by which the mechanism of offset occurs.

Manual and automatic reset

The offset can be removed either manually or automatically. Manual reset uses a potentiometer to electrically offset the proportional band. The amount of proportional band shifting must be done by the operator in small increments over a period of time until the controller power output just matches the process heat demand at the setpoint temperature. This is illustrated in Figures 26 and 27, whilst a controller with manual reset is shown in block diagram form in Figure 28.

Automatic reset uses an electronic integrator to perform the reset function. The deviation (error) signal is integrated with respect to time and the integral is summed, with the deviation signal, to move the proportional band. The output power is thus automatically increased or decreased to bring the process temperature back to setpoint. The integrator keeps changing the output power, and thus the process temperature, until the deviation is zero. When the deviation is zero, the input to the integrator is zero and its output stops changing. The integrator has now stored the proper value of reset to hold the process at setpoint. Once this condition is achieved, the correct amount of reset value is held by the integrator. Should process heat requirements change, there would once again be a deviation which the integrator would integrate and apply corrective action to the output. The integral term of the controller acts continuously to try to make the deviation zero. This corrective action has to be applied rather slowly, more slowly than the speed of response of the load, otherwise oscillations will occur.

Automatic reset action is expressed as the integral time constant.

Definition: The reset time constant is defined as the time interval in which the part of the output signal due to the integral action increases by an amount equal to the part of the output signal due to the proportional action, when the deviation is unchanging.

A controller with automatic reset is shown in block diagram form in Figure 29.

If a step change is made in the setpoint, the output will immediately increase, e.g. as shown in Figure 30. This causes a deviation error which is integrated producing an increasing change in controller output. The time it takes for the output to increase another 10 % is the reset time – five minutes in the example.

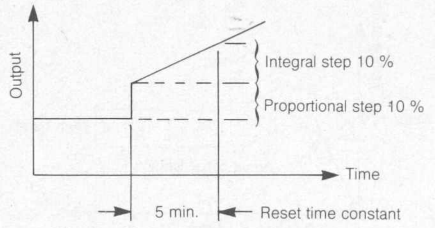

Figure 30. Definition of reset time.

The automatic reset action may also be expressed in repeats per minute and is related to the time constant by the inverse relationship:

Repeats per minute =
1/(Integral time constant (minutes))

A phenomenon called 'integral saturation' is associated with automatic reset. Integral saturation refers to the case when the integrator has acted on the error signal when the temperature is outside the proportional band. The resulting large output of the integrator causes the proportional band to move so far that the setpoint is outside the band. The temperature must pass the setpoint before the controller output will change. As the temperature crosses the setpoint, the deviation signal polarity changes and the integrator output starts to decrease or 'de-saturate'. The result has been a large temperature overshoot. This can be prevented by stopping the integrator from acting if the temperature is outside the proportional band. This function is

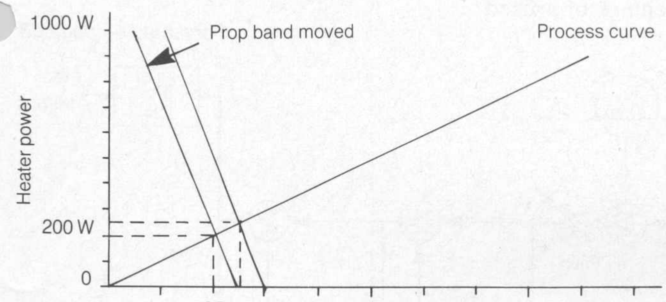

Figure 26. Manual reset action: heater power vs temperature.

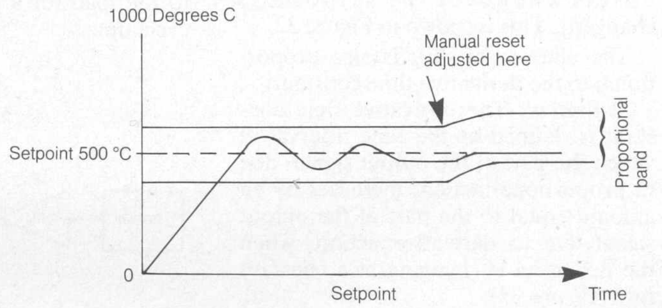

Figure 27. Manual reset action: temperature vs time.

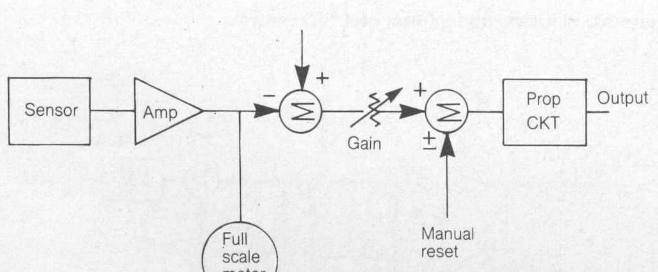

Figure 28. Block diagram of proportional controller with manual reset.

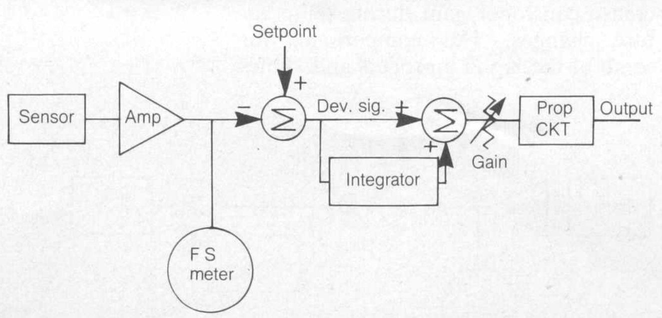

Figure 29. Block diagram of proportional controller with integral action.

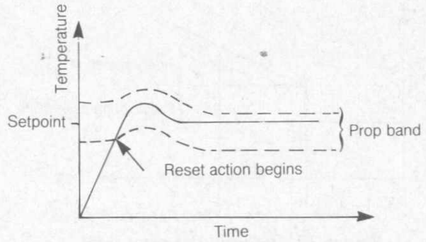

Figure 31. Proportional plus integral action.

called 'integral lockout' or 'integral desaturation'.

One characteristic of all proportional plus integral controllers is that the temperature often overshoots the setpoint on start-up. This occurs because the integrator begins acting when the temperature reaches the lower edge of the proportional band. As the temperature reaches the setpoint, the reset action has already moved the proportional band higher causing excess heat output. As the temperature exceeds the setpoint, the sign of the deviation signal reverses and the integrator brings the proportional band back to the position required to eliminate the offset (Figure 31).

Derivative action (rate action)

The derivative function in a proportional plus derivative controller provides the controller with the ability to shift the proportional band either up or down to compensate for rapidly changing temperature. The amount of shift is proportional to the rate of temperature change. This is accomplished electronically by taking the derivative of the temperature signal and summing it with the deviation signal. (Some controllers take the derivative of the deviation signal which has the side effect of producing upsets whenever the setpoint is changed). This is shown in Figure 32.

The amount of shift is also proportional to the derivative time constant.

Definition: The derivative time constant is defined as the time interval in which the part of the output signal, due to proportional action, increases by an amount equal to the part of the output signal due to derivative action, when the deviation is changing at a constant rate (Figure 33).

Derivative action functions to increase controller gain during temperature changes. This compensates for some of the lag in a process and allows the use of a narrower proportional band with its lesser offset. The derivative action can occur at any temperature even outside the proportional band and is not limited as the integral action is. Derivative action can help to reduce over-shoot on start-up.

PID control

A three mode controller combines the proportional, integral and derivative actions and is usually required to control difficult processes. A block diagram for a three mode controller is shown in Figure 34.

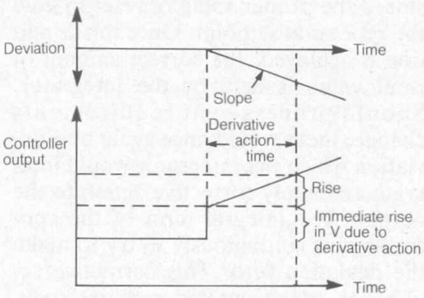

Figure 33. Definition of derivative time.

This system has a major advantage that in a properly tuned controller, the temperature will approach the setpoint smoothly without overshoot because the derivative plus deviation signal in the integrator input will be just sufficient for the integrator to store the required integral value by the time the temperature reaches setpoint.

Proportional controller outputs

The proportional controller output may take one of several forms and the more common forms are time proportioning and current proportioning. In a time proportioning output, power is applied to the load for a percentage of a fixed cycle time.

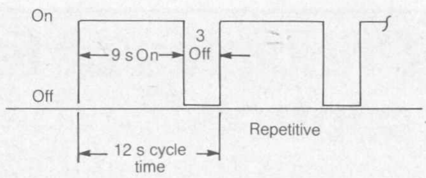

Figure 35. Time proportioning at a 75% level.

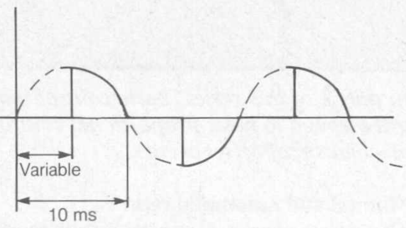

Figure 36. Phase angle fired (or stepless control) output.

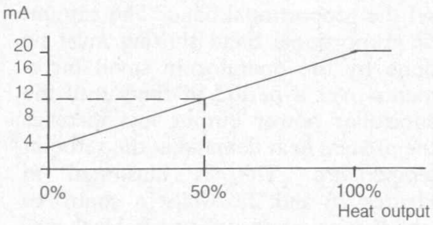

Figure 37. Current proportioning output.

Figure 35 shows the controller output at a 75 % output level for a cycle time of 12 s. This type of output is common with contactors and solid state devices. An advantage of solid state devices is that the cycle time may be reduced to 1 s or less. If the cycle time is reduced to one half the line period (10 ms for 50 Hz), then the proportioning action is sometimes referred to as 'stepless control' or phase angle control. A phase angle fired output is shown in Figure 36.

The current output, commonly 4 to 20 mA, is used to control a solid state

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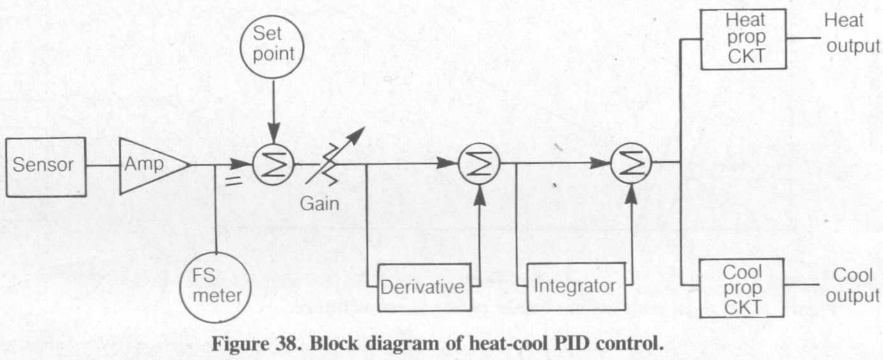

Figure 38. Block diagram of heat-cool PID control.

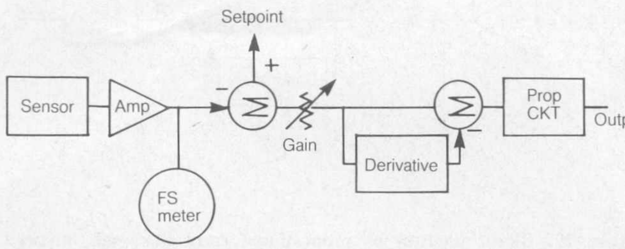

Figure 32. Block diagram of proportional plus rate controller.

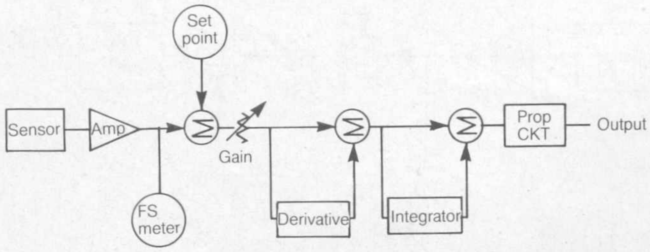

Figure 34. Block diagram of PID controller.

Balancing flue gas flow

Thermal dispersion meter helps maximize scrubber performance

When flyash-laden flue gas flows from one or more boilers to multiple scrubber modules a serious problem is balancing the flow to the modules so that each operates at its maximum efficiency. Poor scrubber performance results not only in increased sulphur dioxide emissions, but also in pluggage of mist eliminators and reheater and corrosive damage to downstream components.

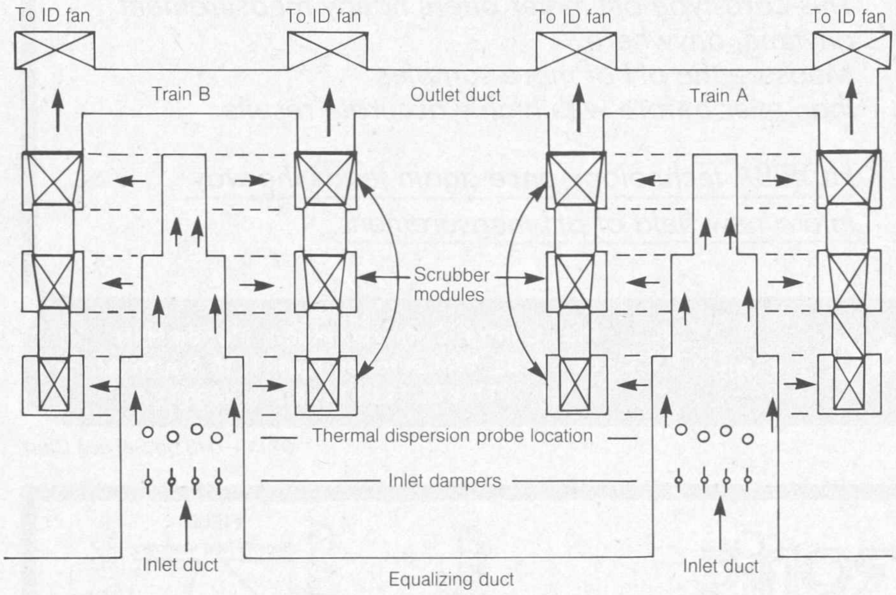

Figure 1. Arrangement of scrubber modules.

This was the problem at the Sherburne County powerplant of Northern States Power Co, Becker, Minn, where two 750 MW units each exhaust through equalizing ducts to 12 scrubber modules arranged in two trains (Figure 1). In the original design, flow to the modules was balanced by mechanically adjusting the venturi-section gap at the inlet to each module.

The problem was flow measurement. Originally, flow was determined by measuring the pressure differential across the venturi rod section and inferring the flow rate from this. The position of the pressure taps is shown in Figure 2. The problem with this technique was that lime buildup on the rod venturi section altered the pressure drop as much as changes in gas flow. As a result, powerplant personnel had no reliable way of knowing how much flue gas was flowing to each scrubber module, although they knew they were not getting balanced flow because of the excessive maintenance needed on the front row of modules.

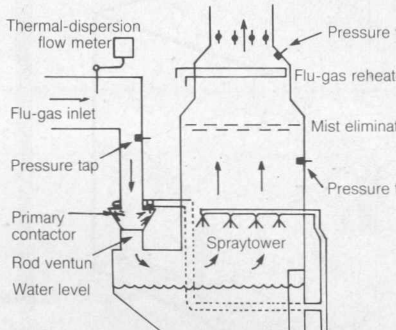

Figure 2. Basic arrangement of a scrubber module.

After some experimentation, the problem was solved using thermal-dispersion meters supplied by Fluid Components Inc (FCI). In the initial installation, a test flowmeter was installed at the scrubber outlet, above the flue-gas reheater. Although the flue gas is cleaner there, the location proved to be inadequate because too many environmental factors could affect the probe's performance. For instance, plugged reheat sections could force air to flow through localized areas, creating artificially low or high velocities, depending on the probe's location.

The probe was then moved to the scrubber inlet. At this location, process temperatures are between 120 and 176 °C and the flue gas contains large quantities of corrosive flyash. To solve these problems a probe rated at 450 °C, with a nickel-plated coating to resist flyash abrasion, was used. Success with it led to the installation of similar

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power device, a motor operated valve positioner, motor operated damper, or saturable core reactor. The relationship between controller current output and heat is shown in Figure 37.

Heating/cooling option

Certain applications, which are partially exothermic, demand the application of cooling as well as heating, and to achieve this, the controller output is organised as shown in Figure 38.

The controller has two proportional outputs, one for heating and one for cooling. Below the proportional band (Figure 39) full heating is applied and above the proportional band full cooling is applied. Within the proportional band (Xp1) there is a linear reduction of heating to zero followed by a linear increase in cooling, with increasing temperature. Heating and cooling can be overlapped (Xsh) to ensure a smooth transition between heating and cooling. In addition, to optimise the gain be-

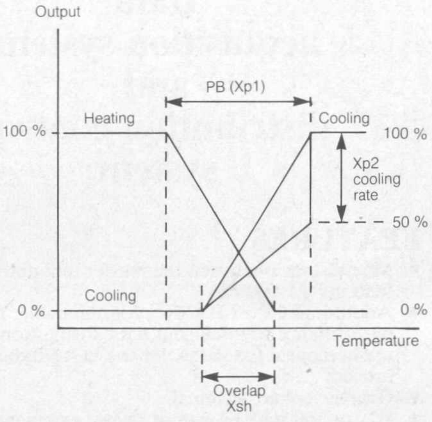

Figure 39. Transfer function for heat-cool PID control.

tween heating and cooling action, the cooling gain is made variable Xp2.

(To be continued)

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